LAYCOCK

The Germination of
the Pumpkin Seed

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THE GERMINATION OF THE PUMPKIN SEED

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED The Germination of the Pumpkin Seed

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

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THE GERMINATION OF THE PUMPKIN SEED

The study of the germination of the pumpkin seed, as a representative of the Cucurbitaceae, is of peculiar interest. This arises from two singularities of the seed: its extremely flattened shape and the existence of an unusually tough and hard testa. These characteristics of the testa necessitate some method which will enable the seedling in its germination to escape the confines of the seed.

The pumpkin seed, because of its peculiar form, may take one of several positions in the earth. For instance, the seed may lie flat or edgewise, or may stand erect. Noll and others have claimed that the germination is affected by the position of the seed, not all positions being equally advantageous for the developing seedling. It is, therefore, a matter of interest to know which position of the several is the most favorable one.

Tscherning,Noll and others, in their investigations, have found that in germination, the seedlings of Cucurbitaceae form a special organ, the peg or "Stemmorgan" at point of union of the root and hypocotyl. The peg is formed on the concave side of the hypoctyl and fastens itself by root-hairsto the lower of the two testa-valves. The peg acts as a fulcrum and the hypocotyl as the lever. As it grows, the hypocotyl, by means of its leverage, pushes upon the opposite testa-valve and separates the two; thus the seedling is released. The peg or "Stemmorgan" seems to be

formed at a time when it is needed to assist in tearing apart the two valves of the testa. This function seems to be its sole work. Investigation however shows that the pegs vary and that the differences in the form and the location of the peg are dependent largely upon the position of the seed during its germination.

The form and location of the peg during germination has been made the subject of investigation by Tscherning,Flahault, Francis Darwin, and other prominent botanists. To Professor F. Noll, however, who has most recently investigated the germination of the pumpkin seed, belongs most of the credit for work done in this direction. The results of his investigations were published in the "Landwirtschaftliche Jahrbücher" for 1901, in an article entitled, "Zur Keimungs Physiologie der Cucurbitaceen". Professor Noll's results, as stated in that article, suggested the work with which the present paper has to do, and reference will therefore be made to it, as occasion arises.

These peculiarities of the pumpkin seed - the shape, and the hardness of the testa - suggest the problems to be here discussed. These, briefly stated, are as follows:

I. Is one position of the seed more favorable than another for germination? If so, what is the most favorable position?

II. How is germination affected by different degrees of moisture?

III. How is germination affected by differences of temperature?

IV. How does the position of the seed affect the form and position of the peg?

I.

GERMINATION AS AFFECTED BY THE POSITION OF THE SEED

Noll states, as the result of his investigations in this direction, that the most favorable position for germination is a horizontal one, with the flat surface directed downward. The most unfavorable is the edgewise or "hochkant," according to Noll.

The positions in which these seeds were placed by Noll were identical with those in the experimentsto be given here, and as a matter of convenience the letters will be used to designate these positions:

v. u. - vertically placed, with the hilum directed upward.

v. d. - vertically, with the hilum downward.

h. e. - horizontally, resting on edge.

h. f. - horizontally, resting upon the flat surface.

o. u. - obliquely upward, 30° to 45° from the perpendicular, hilum upward.

o. d. - obliquely downward, with hilum downward.

Experiment I. The seeds used in this and all succeeding experiments were Cucurbita pepo, variety Connecticut Field. No seeds were actually planted, but only thrust into the sand or sawdust far enough to be held in position. Before planting for the preliminary experiment, the seeds were soaked in tap-water at the temperature of the room for twenty-four hours. During this time the seeds floated in a horizontal position with the flat surface uppermost. At the end of the twenty-four hours, the seeds were planted in a crock of sand, from four to six seeds being planted in each of the six positions just described. The sand had been

made moderately damp and had been thoroughly mixed to secure a uniform moisture throughout. The seeds were thrust into the sand only far enough to be held in position and were covered with several thicknesses of moist filter paper which was removed and dampened every day. Over the whole a crock was inverted to retain the moisture. The temperature was that of the laboratory, 24° C. At the expiration of six days the total germinations were as follows: v. u. 83 per cent, o. u. 83 per cent, o. d. 83 per cent, h. e. 75 per cent, h. f. 50 per cent and v. d. 25 per cent. Noll names only the most favorable and least favorable positions.

The position, h. f., which according to Noll's results should have shown the highest per cent of germination, is seen to have been the next to lowest; h. e., which Noll found to be the least favorable position in this experiment has a much higher per cent of germination than h. f.

A series of experiments II. was next performed. Seeds were treated as in the preceding, with the exception that they were planted in saw-dust. The bowls were then placed in rooms of different temperatures, which were approximately 22°, 24° and 35° C.

Series III., IV., V., and VIII. were identical with II., excepting that the seeds were in sand instead of saw-dust. In V. and VIII. the number of seeds in each member of the series was greater, there being 10 seeds in each.

To determine whether or not, the contact between the seedling and the particles of earth, had caused the formation of the peg, an experiment was tried in which moist air was the medium. The results of this experiment were included in the data for determining the most favorable position of the seed.

Experiment VI. The seeds, 25 for each position, were germinated in petri dishes between moist filter papers. Thus, moist air instead of sand became the medium in which the seeds were germinated. Much difficulty occurred here in keeping the seeds in the required position throughout the whole time. Many of these seeds, too, were attacked by mould.

Tables showing the total per cents of germination for each of these experiments, from day to day, are given below. No count was made on Sundays, therefore the average was, in some cases, lowered for a day or two.

TABLE I.

PER CENT GERMINATING IN ONE DAY AFTER PLANTING

Exp. No.	I.	II.			III.			IV.			V.			VI.	VIII.			Average percent on 119-145 seeds.
No. seeds.	4-6	2 to 4			3 to 6			5 to 8			10			25	10			
Temp.	24°	22°	24°	35°	22°	24°	35°	22°	24°	35°	22°	24°	35°	24°	22°	24°	35°	
v. u.	0	0	0	25	0	0	0	0	0	0	0	0	0	0	0	0	20	2.6
v. d.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	.1
h. e.	0	0	0	25	0	0	0	0	0	0	0	0	0	0	10	0	0	.2
h. f.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	.5
o. u.	0	0	0	0	0	0	0	0	0	40	0	0	0	0	0	0	10	2.9
o. d.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	30	1.7

TABLE II.

PER CENT GERMINATED TWO DAYS AFTER PLANTING

Exp. No.	I.	II.			III.			IV.			V.			VI.	VIII.			Average percent on 119-145 seeds.
No. seeds.	4-6	2 to 4			3 to 6			5 to 8			10			25	10			
Temp.	24°	22°	24°	35°	22°	24°	35°	22°	24°	35°	22°	24°	35°	24°	22°	24°	35°	
v. u.	50	25	0	25	50	0	75	33	12	33	0	40	0	0	60	30	50	28.4
v. d.	25	0	0	25	25	0	25	0	0	33	0	20	0	0	60	40	60	18.4
h. e.	75	50	0	25	0	0	25	16	43	33	0	20	10	0	50	30	60	19.5
h. f.	16	0	0	0	25	0	50	0	28	20	0	30	30	0	80	30	40	25.3
o. u.	50	0	0	50	50	0	33	20	12	40	10	20	10	0	50	20	40	23.6
o. d.	33	0	0	25	75	0	0	20	0	20	0	0	0	0	50	40	50	18.4

TABLE III.

PER CENT GERMINATED THREE DAYS AFTER PLANTING

Exp. No.	I	II.			III.			IV.			V.			VI.	VIII.			Average percent on 119-145 seeds.
No. seeds.	4-6	2 to 4			3 to 6			5 to 8			10			25	10			
Temp.	24°	22°	24°	35°	22°	24°	35°	22°	24°	35°	22°	24°	35°	24°	22°	24°	35°	
v. u.	66	No Record	50	50	50	20	75	50	62	50	10	60	10	24	No Record			44.4
v. d.	25		0	0	75	33	50	20	14	33	30	60	0	16				27.4
h. e.	75		0	0	33	0	25	33	43	33	10	50	20	16				26.0
h. f.	33		0	0	75	50	50	20	86	20	10	50	40	20				34.8
o. u.	83		50	50	75	0	33	40	62	40	30	30	10	16				39.9
o. d.	33		0	0	75	16	0	40	28	40	10	10	0	16				20.6

TABLE IV.

PER CENT GERMINATED FOUR DAYS AFTER PLANTING

Exp. No.	I.	II.			III.			IV.			V.			VI.	VIII.			Average percent on 119-145 seeds.
No. seeds.	4-6	2 to 4			3 to 6			5 to 8			10			25	10			
Temp.	24°	22°	24°	35°	22°	24°	35°	22°	24°	35°	22°	24°	35°	24°	22°	24°	35°	
v. u.	83	25	No Record	25	50	20	75	No Record	62	No Record	10	70	10	36	70	50	60	46.1
v. d.	25	33		25	75	33	50		28		30	60	0	28	90	60	60	42.7
h. e.	75	50		25	33	0	25		43		10	60	30	16	80	60	60	40.5
h. f.	33	0		0	75	66	50		86		10	60	40	20	100	50	60	46.4
o. u.	83	50		50	75	20	33		62		30	50	10	28	80	80	50	50.0
o. d.	66	66		25	75	33	0		28		10	10	0	28	60	80	60	38.6

TABLE V.

PER CENT GERMINATED FIVE DAYS AFTER PLANTING

Exp. No.	I.	II.			III.			IV.			V.			VI.	VIII.			Average percent on 119-145 seeds
No. seeds.	4-6	2 to 4			3 to 6			5 to 8			10			25	10			
Temp.	24°	22°	24°	35°	22°	24°	35°	22°	24°	35°	22°	24°	35°	24°	22°	24°	35°	
v. u.	83	25	50	25	50	40	75	50	No Record	50	10	80	20	44	80	50	60	50.1
v. d.	25	33	0	25	75	33	50	22		50	30	60	0	48	90	60	60	41.2
h. e.	75	50	0	25	33	50	25	33		50	10	60	30	28	80	60	60	40.5
h. f.	50	0	50	0	75	66	75	20		20	20	60	40	28	100	50	60	44.6
o. u.	83	50	50	50	75	20	33	40		40	40	50	10	32	80	80	50	48.9
o. d.	66	66	0	25	75	50	33	60		40	20	10	0	40	60	90	60	43.4

TABLE VI.

PER CENT GERMINATED SIX DAYS AFTER PLANTING

Exp. No.	I.	II.			III.			IV.			V.			VI.	VIII.			Average percent on 119-145 seeds.
No. seeds.	4-6	2 to 4			3 to 6			5 to 8			10			25	10			
Temp.	24°	22°	24°	35°	22°	24°	35°	22°	24°	35°	22°	24°	35°	24°	22°	24°	35°	
v. u.	83	25	50	25	50	40	75	50	62	50	10	80	20	52	90	50	60	51.3
v. d.	25	33	0	25	75	33	50	20	28	66	30	60	10	48	90	60	60	41.9
h. e.	75	50	0	25	33	50	25	36	57	50	20	60	30	36	80	70	60	44.7
h. f.	50	0	50	0	75	66	75	20	86	20	20	60	40	32	100	50	60	47.3
o. u.	83	50	20	50	75	40	33	40	87	40	40	50	10	36	80	80	50	50.8
o. d.	83	66	100	25	75	66	33	60	43	40	20	20	0	44	60	90	60	52.0

TABLE VII.

PER CENT GERMINATED SEVEN DAYS AFTER PLANTING

Exp. No.	I.	II.			III.			IV.			V.			VI.	VIII.			Average percent on 119-145 seeds.
No. seeds.	4-6	2 to 4			3 to 6			5 to 8			10			25	10			
Temp.	24°	22°	24°	35°	22°	24°	35°	22°	24°	35°	22°	24°	35°	24°	22°	24°	35°	
v. u.	83	25	50	25	50	40	75	50	62	50	10	80	20	52	90	60	60	51.8
v. d.	25	33	0	25	75	33	50	20	28	60	30	60	20	48	90	60	60	42.5
h. e.	75	50	0	25	33	50	25	36	57	66	20	70	40	44	80	70	60	47.1
h. f.	50	0	50	0	75	66	75	20	86	20	30	70	40	32	100	50	60	48.4
o. u.	83	50	20	50	75	40	33	40	87	40	40	60	10	40	80	90	50	52.2
o. d.	83	66	100	25	75	83	33	60	57	40	20	20	0	44	60	90	60	53.8

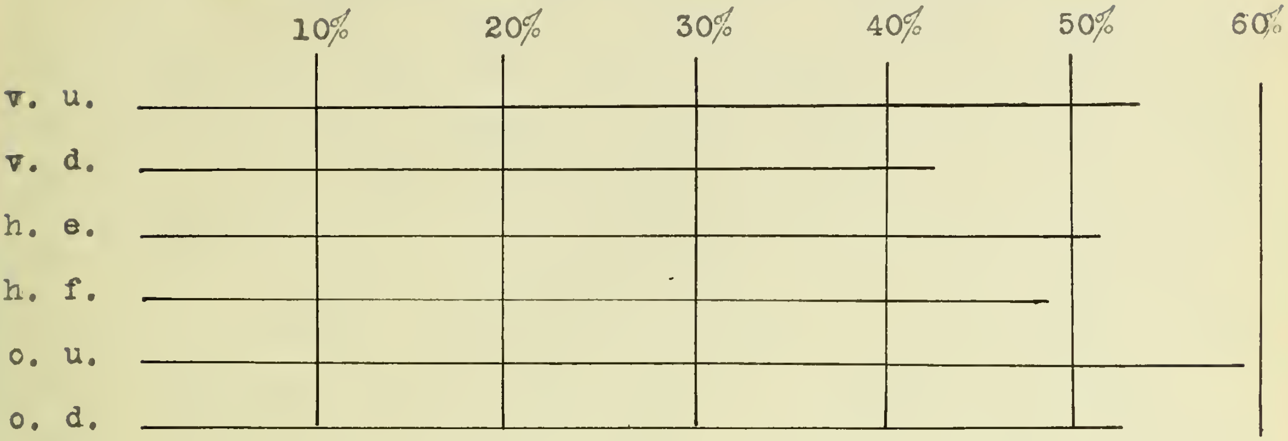
TABLE VIII.

PER CENT GERMINATED EIGHT DAYS AFTER PLANTING

Exp. No.	I.	II.			III.			IV.			V.			VI.	VIII.			Average percent on 119-145 seeds.
No. seeds.	4-6	2 to 4			3 to 6			5 to 8			10			25	10			
Temp.	24°	22°	24°	35°	22°	24°	35°	22°	24°	35°	22°	24°	35°	24°	22°	24°	35°	
v. u.	83	25	50	25	50	60	75	50	62	50	10	80	20	56	90	60	60	53.3
v. d.	25	33	0	25	75	33	50	20	28	66	30	60	20	52	90	60	60	42.7
h. e.	75	50	100	25	33	50	25	36	57	66	20	70	40	44	80	70	60	52.7
h. f.	50	0	50	0	75	66	75	20	86	20	30	70	40	36	100	50	60	48.7
o. u.	83	50	100	50	75	40	33	40	87	60	40	60	10	40	80	90	50	58.1
o. d.	83	66	100	25	75	83	33	60	57	40	20	20	0	44	60	90	60	53.8

DIAGRAM I.

AVERAGE TOTAL GERMINATION FOR THE SIX POSITIONS



These results are also graphically shown in Plate I.

The results obtained from these seven series of experiments confirmed the general results gained from the preliminary experiment (Experiment I.) in regard to the positions of the seeds, although the percentages in the latter were much higher.

Is the germination affected by the position of the seed during the twenty-four hours of soaking?

In the experiment described here the seeds had been inverted as a means for ascertaining, if possible, whether the formation of a peg was induced during the soaking process. To test this, several series of experiments, which differed from the previous ones in the manner of soaking, were next performed. One set of seed were soaked in the usual horizontal position and were then placed in the six positions for germination; another, in the identical positions in which they were to be left to germinate; a third, soaked in the six positions, were, on planting at the expiration of twenty-four hours, turned 180°; the fourth set were treated as the third, but were not turned until twenty-four hours after placing in sand.

Under these four methods of treatment, one and the same method gave the highest per cents of germination for four positions of the seed:- v. u., h. e., h. f., and o. u. This method, it is readily seen from Table IX., was the soaking of the seeds in the six positions, then planting in sand at the expiration of twenty-four hours, and finally turning 180° twenty-four hours after planting. In o. d. position the highest per cent of germination occurred in the seeds which had been soaked in the six positions and turned 180° when planted; while for v. d. position, the seeds soaked and germinated without change of position showed the highest per cent.

TABLE IX.

TOTAL GERMINATION OF SEEDS SOAKED

IN DIFFERENT POSITIONS, AND GERMINATED HILUM DOWNWARD

Position	Soaked in horizontal position. M	Soaked in position for germination. N	Soaked in the six positions. When planted, turned 180°. O	Soaked in the six positions. Turned 180° 24 hrs. after planting. P
v. u.	70%	70%	51%	73%
v. d.	55	67	55	33
h. e.	45	40	65	87
h. f.	55	65	47	67
o. u.	60	35	54	67
o. d.	54	65	74	53

Results of these experiments are graphically shown in Plate II.

II.

GERMINATION AS AFFECTED BY DIFFERENCES IN MOISTURE CONDITIONS

Moisture is evidently a very important factor in the germination of the pumpkin seed, the per cent of germination being very much lowered, when the sand is kept very moist. In one experiment, seeds in very wet sand germinated only to the extent of 26 2/3 per cent, but on repeating the experiment with dryer sand, 52 1/2 per cent germinated. Noll seems to have made no experiments dealing with different degrees of moisture.

Experiment XIV. An experiment with moisture, as a chief factor, was planned as follows:

A quantity of sand was so mixed as to be uniform throughout as to moisture conditions. Five crocks were partially filled with this sand. Into the sand of the first crock was mixed 50 cc. of water. The next crockful was saturated, requiring 390 cc. to accomplish this. The third had a quantity of water which was intermediate between these two, approximately 220 cc. The fourth had 135 cc. and the last 305 cc. This method was employed simply as a means for getting different degrees of moisture, hence the quantities used were not exact, but only approximate. There were thus five crocks in the series having respectively 50 cc., 135 cc., 220 cc., 305 cc. and 390 cc. of water. For this experiment the seeds were differently prepared from the method described in previous experiments. One hundred seeds were soaked in a vertical position with the hilum directed upward; 50 were soaked in a vertical position with the hilum downward; and an equal number soaked in a horizontal position. After soaking for twenty-four hours,

all were ready for the sand, which had just been prepared. For each of the five crocks the seeds were treated as follows:

After marking off the surface of the sand in each crock into quarters, in one space, with the hilum directed downward, were planted 10 seeds which had soaked while occupying a horizontal position; in the second quarter were placed, hilum downward, 10 seeds which had retained that position during the soaking; in the third were placed 10 seeds which had been soaked with the hilum upward, and hence a turn of 180° was now necessary to bring these into the same position as those in the first and second quarters. In the fourth quarter, hilum still directed upward, were planted the seeds which had been soaked in that position. These were not turned until twenty-four hours later, having retained this position for forty-eight hours. These crocks, of 40 seeds each, after having been covered with damp filter paper, were covered with inverted crocks, and set in an even temperature room at about 22° C. to germinate.

Most of the seeds germinated during the first three days. Percentages for these days are given in Table X.

TABLE X.

PER CENT OF GERMINATION FOR FIRST THREE DAYS, UNDER DIFFERENT MOISTURE CONDITIONS, HILUM DIRECTED DOWNWARD IN GERMINATIO

Amount water.	50 cc.			135 cc.			220 cc.			305 cc.			390 cc.		
Position for soaking.	Days			Days			Days			Days			Days		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Horizontal	20	70	80	10	60	60	20	50	50	0	70	90	10	20	40
Hilum downward	30	50	70	10	30	40	0	20	20	10	20	20	10	40	40
Hilum upward; planted hilum downward	50	60	70	0	10	10	0	10	10	40	50	50	0	0	0
Hilum upward. Turned 180° 24 hrs. after planting	30	40	40	20	50	50	20	20	20	10	10	30	20	30	40

Because most of the seeds in this series of experiments germinated during the first three days and because the per cents for those days varied so greatly for position as well as for moisture, I give Table X, showing the total germinations for days 1, 2 and 3. A study of this table shows the complete lack of uniformity in general. It is, however, easily seen that the horizontal position for soaking is the most favorable. This is shown more clearly in Table XI. which gives the total germinations.(See also Plates III., IV., V., and VI.). The latter table also shows the crock containing 50 cc. to be the most favorable moisture condition for seeds soaked in either of the two vertical positions; the crock contain-

ing 305 cc. seems to be the most favorable for seeds soaked in the horizontal position and the crock containing 135 cc. for seeds soaked hilum upward and kept in that position for twenty hours after planting.

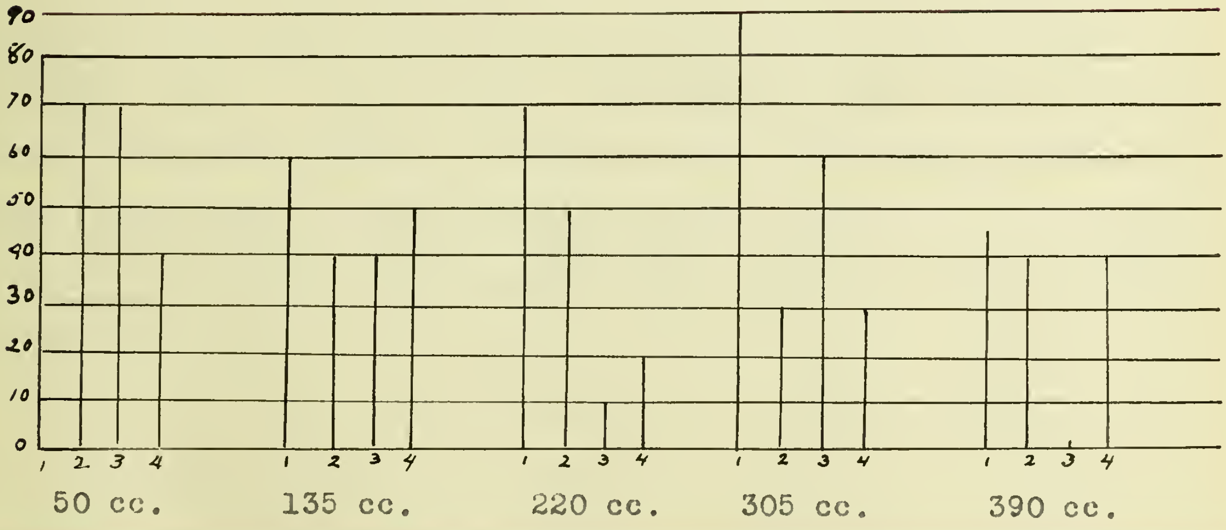
TABLE XI.

TOTAL GERMINATIONS UNDER DIFFERENT MOISTURE CONDITIONS

HILUM DIRECTED DOWNWARD

Position for soaking.	50 cc.	135 cc.	220 cc.	305cc.	390 cc.
Horizontal	80	60	70	90	44
Vertical, hilum downward.	70	40	50	30	40
Vertical, hilum upward.	70	40	10	60	0
Vertical hilum upward and for 24 hrs. after planting.	40	50	20	30	40

DIAGRAM 2 (TO ILLUSTRATE TABLE XI.)



III.

GERMINATION AS AFFECTED BY DIFFERENT CONDITIONS OF TEMPERATURE

Noll states that pumpkin seeds should not be kept at too high a temperature during germination and cites as his reason that the too rapid germination, when the seeds are kept quite warm, carries the hypocotyl out of the testa before the formation of the peg. The seedling, consequently has difficulty in freeing itself, unaided, from the testa. It may, however, be readily demonstrated that the per cent of germination is not so high when the seeds are placed in a temperature which is above the optimum temperature for the germination.

To test this the following experiments were used:

Experiment II. Seeds were soaked in a horizontal position, for twenty hours, planted in saw-dust in each of the six positions (v. u., v. d., h. e., h. f., o. u., o. d.) and covered with moist filter paper and an inverted crock. Three crocks were so prepared, the conditions of moisture being identical. One crock remained in a room of the temperature of 24° C.; one was placed in a room of about 35° C. and the third in an even-temperature room of 22° C. This experiment was repeated four times, using sand instead of saw-dust. In the five series of experiments there were from 30 to 38 seeds in each position at each of the three temperatures. By these experiments it was possible to find the most favorable temperature and the most advantageous seed position at that temperature.

TABLE XII.

TOTAL GERMINATION OF SEEDS GERMINATED AT 22°

Position	1 da.	2 da.	3 da.	4 da.	5 da.	6 da.	7 da.	Total 8 da.
v. u.	0%	34%	37%	39%	43%	45%	45%	45%
v. d.	0	19	42	57	50	50	50	50
h. e.	2	23	25	43	41	44	44	44
h. f.	0	21	35	46	41	43	45	45
o. u.	0	26	48	59	57	57	57	57
o. d.	0	29	38	52	50	56	56	56

TABLE XIII.

TOTAL GERMINATION OF SEEDS AT A TEMPERATURE OF 24°

Position	1 da.	2 da.	3 da.	4 da.	5 da.	6 da.	7 da.	Total 8 da.
v. u.	0%	14%	48%	50%	55%	56%	58%	62%
v. d.	0	12	27	45	38	36	36	36
h. e.	0	19	23	41	42	47	49	69
h. f.	0	18	46	65	56	62	64	64
o. u.	0	10	35	52	50	55	59	75
o. d.	0	8	13	38	37	64	70	70

TABLE XIV.

TOTAL GERMINATION OF SEEDS AT A TEMPERATURE OF 35° C.

Position	1 da.	2 da.	3 da.	4 da.	5 da.	6 da.	7 da.	Total 8 da.
v. u.	9%	37%	46%	42%	46%	46%	46%	46%
v. d.	4	29	21	34	37	42	44	44
h. e.	5	31	19	35	38	38	43	43
h. f.	2	28	27	37	39	39	39	39
o. u.	10	35	33	36	37	37	37	41
o. d.	6	19	10	21	32	32	32	32

Plates VII., VIII. and IX. also show the results of germination at the three different temperatures.

The table below gives a comparison in the total germinations of seeds germinated at the three different temperatures. At a glance, it will be seen that 24° C. is the optimal temperature for five out of six positions, a higher per cent germinating in the positions v. u., h. e., h. f., o. u., and o. d.

TABLE XV.

AVERAGE TOTAL GERMINATIONS

UNDER DIFFERENT CONDITIONS OF TEMPERATURE

Position	22°	24°	35°	Average
v. u.	46	62	45	51
v. d.	44	36	50	43
h. e.	43	69	44	52
h. f.	39	64	45	49
o. u.	41	75	57	58
o. d.	32	70	56	52

IV.

FORM AND POSITION OF THE PEG

The last problem to be discussed is, How does the position of the seed during germination affect the form and position of the peg?

The peg, or Stemmorgan, as Noll calls it, is a tissue-swelling formed on the concave side of the curving hypocotyl at its point of union with the root. According to Noll, all parts of the hypocotyl are equally qualified to form this peg, but the broader sides of the elliptical stem opposite the halves of the testa seem to develop more of these tissue-cells than the narrower sides. This peg is a swelling, often rising abruptly from the hypocotyl, formed in from 24 to 48 hours. It varies in shape with the different positions of the seeds during germination. When the seed lies flat upon the earth, the peg forms on the concave side of the hypocotyl where alone it could be effective. It fastens itself by numerous root-hairs to the lower half of the testa. Thus firmly fixed to the lower half, the hypocotyl in its rapid growth pushes upon the upper half of the testa and thus pushes apart the two valves of the shell. In this manner the seedling is released from the testa.

Noll found pegs of four different shapes or forms. He observed that these differences in form were due to differences in the position of the seed during the period of germination. When seeds lay flat upon the earth or occupied a vertical position with the hilum up, the peg was formed on the concave lower side of the stem. In seeds occupying a horizontal edgewise position, a swell-

ing appeared on the lower side of the hypocotyl, but the tissue-swelling was greater opposite the right and left valves than it was on the lower side, between the valves. In seeds planted in a vertical position with the hilum downward the peg assumed the form of a frill which completely encircled the stem. In seeds obliquely placed in the earth with the hilum downward Noll found a pronounced peg on the lower side and one less pronounced on the upper side opposite to the first.

Experiments similar to those of Noll were performed, the simplest of which was as follows:

Three hundred seeds were soaked for 24 hours in a horizontal position in tap-water, at the temperature of the room. The next day crocks of sand were prepared in which very dry sand was mixed with 50-60 cc. of water. The moisture was uniform for the six crocks. At the expiration of the 24 hours of soaking, the seeds were placed in the sand, fifty in each crock. In the first crock the seeds occupied the position v. u.; in the second the seeds were placed in the v. d. position. The third crock contained seeds placed in the h. e. position; the fourth contained those in the h. f. position. Seeds in the o. u. position were in the fifth crock and seeds in the o. d. position occupied the last crock. The surface of the sand was covered with damp cheese cloth and over the whole a crock was inverted. The seeds were kept at laboratory temperature, about 24°. The cheese cloth was removed and dampened each day.

The sixth day after planting, the germinated seeds were examined as to peg formation. Many seeds which had germinated showed dead seedlings. Most of these were so young that the peg was

not developed sufficiently to show the form of the peg. Of such seeds, no record as to the peg could be made.

Of the seeds in position h. f., 80 per cent of those which germinated formed the peg on the concave side, as Noll describes it. The other 20 per cent were dead. Of 34 per cent of the seedlings in position h. e. the form of the peg was unrecorded, but all the others except 7 per cent had pegs similar to Noll's. In all the other positions, the results of the experiments showed no uniformity in the shape of the peg. Only 3 per cent of the seeds planted in the o. d. position produced a peg shaped as Noll pictures it in Fig. 3 of his article. A singular formation in the hypocotyls of seeds in this position was noted in about one-third of those cases in which the peg was formed on the concave side only. This singularity was a conspicuous increase in the diameter of the hypocotyl for a length of several centimeters just above the peg.

In not a single instance among seeds in the position v. d. was a frill found, as is pictured by Noll in Fig. 2.

It may be clearly seen that the results of this experiment do not tally with those of Noll except as tothe h. e. and h. f. positions. Also, that, at least in this variety of pumpkin, "Connecticut Field", the position of the peg is not constant for any positions except h. f. and h. e. For these positions it may be said to be constant.

In other similar experiments, however, ring formations were found, although these were not frills as Noll pictures. In two crocks of seeds, one of which was kept very moist and the other much dryer, only 35 per cent of the 20 seeds germinated. Of the

whole number planted, 14 per cent showed the ring formation. In another experiment consisting of the same number of seeds similarly treated, 21 per cent had the ring swelling. In a third experiment, 34 per cent had the ring swelling. Hence in these four experiments the ring swellings were respectively 0 per cent, 14 per cent, 21 per cent and 34 per cent, but these were not frills as Noll describes. In many cases, pegs which I classified as ring-swellings were really mere half-rings or single pegs, decreasing in size as they encircled the hypocotyl, so that often on the convex side there was barely any visible swelling. One case of an unmistakable frill however, was found among hundreds of seedlings examined. In this case there could be no doubt that the frill was such as Noll had found in his investigations, and which he leads us to believe was constant, or, at least, characteristic. Many showed one or two pegs more or less distinct, with a semblance of a ring in addition. These forms and positions, as is plainly seen, were the resultants, in many instances, of one position for the soaking of the seed and a different one for the planting.

A great variety in the shapes of pegs was found. In five cases, the seedling seemed to be stunted, injured or abnormal; in seven instances there was no swelling of any sort on the hypocotyl. One of these was in a seed in an oblique position turned 180° which according to Noll should have shown the double peg; the other six were found in seeds germinated in the v. d. position, hence these should have shown the ring swelling. Many of the seeds which bore the two pegs, opposite each other were in the v. d. position, hence we ought to find some connection between the

two-pegged and the frill forms, if Noll's results be true.

One seedling, turned in the last named position after it had been placed for forty-eight hours with hilum upward, bore three very distinct pegs of almost equal size. Two bore pegs only on the convex side of the hypocotyl. One of these had been soaked horizontally and had then been placed in o. d. position; the other also was germinated in the o. d. position, after having been turned 180°. Some showed a very slight ring, others a slight peg only. In the experiments where ring formations were found, it was true in every case that the number of seedlings having a one-sided peg was greater than the number of those having a ring-swelling. Hence the frill is almost unknown, and the ring formation certainly is not characteristic for seeds of variety "Connecticut Field" in the v. d. position.

A general study of the relation of the peg to the seedling led Noll to the definite conclusion that gravity was the principal stimulus to which the formation of the peg was due. This explained every case in which the peg was found to be on the lower side of the stem. It was necessary, however, to explain such peg formations as that of the seed in the h. e. position, in which the greatest swelling is not on the lower side. For want of a more definite name, Noll calls this second force "autonom". He is able to explain the frill in the v. d. position as due to gravity and to a form of response other than positive geotropism.

Noll believed, also, that the formation of a peg might be induced, i. e., if the seed were placed in such a position as would cause a conspicuous peg to form, the seed might be turned before the swelling began, but the irritation which would have

produced the first swelling would continue and would produce the peg as certainly as if the seed had remained in the first position.

Noll was able to bring about the formation of a second peg opposite the first, by turning the seedlings 180° after the first peg had been formed. Observations on seeds germinated hilum downward after being turned 180° gave a number of seedlings bearing two pegs. Of seeds turned after the 24 hours of soaking there was in three experiments an average of 15 per cent showing a second peg, while those turned after 48 hours, there was 14 per cent. Yet, of seeds soaked hilum downward and germinating in the same position, there was 12 per cent of the seedlings which had a peg, on the convex side. Hence, the turning of the seed 180° produced changes in the pegs of but a few seeds in this experiment.

In another series of experiments in which the turning of 180° was from position o. u. to that of o. d., the per cents of seedlings which bore the second peg were only from 7 per cent to 10 per cent.

Induction, therefore, may be a factor in the formation of the peg, but if so it is of slight importance.

In germinating the seeds in sand or saw-dust, some of the seeds in positions o. d. or v. d. in early germination changed their positions in the soil because the bend in the hypocotyl seemed to rest upon the sand and so bring the seed to almost an h. e. or h. f. position. To prevent or overcome this, those seeds afterward had a hole made for them in the sand or saw-dust so that the hypocotyl and root could take their natural positions. Experiments were tried in which seeds were germinated in moist air to avoid all contact stimuli. The results, however, were not greatly

different from those obtained in seeds germinated in moist sand.

Noll tried numerous experiments to determine whether or not contact acted as a stimulus in peg-formation. One experiment was the removal of both testa-valves that no contact might occur between them and the embryo. He concluded that contact, as well as induction had no part in this formation. That the peg-formation was not due to the stimulus of gravity acting alone, but to at least two stimuli acting in conjunction, was very evident. This unknown stimulus for want of a more definite name, Noll designated as "autonom".

SUMMARY

The seeds of the pumpkin do not germinate equally well in all positions. The oblique position with the hilum upward is the most favorable position for the germination of the "Connecticut Field" variety of pumpkin. This does not agree with the results of Noll who claims the horizontal flat position is the most favorable.

The oblique position with the hilum downward and the vertical position with the hilum upward are almost equally favorable. The least favorable position was found to be the vertical with the hilum downward. Noll, however, found the least favorable to be the horizontal edgewise position.

Seeds did not germinate at the same rate in all positions. Seeds in the oblique position with hilum upward germinate more rapidly after the third day. Seeds in oblique position with the hilum downward germinate more rapidly after the fifth day.

Pumpkin seeds do not require much moisture. A soil that is rather dry is the best suited to the germination of these seeds.

In a moist soil the seeds are liable to mould or decay.

Of the three temperatures, 22°, 24°, 35°, in which seeds were germinated, 24° seems most favorable. This was the temperature of the laboratory and was not, therefore, a constant temperature. This was the optimal temperature for seeds in all the six positions except those in vertical position with the hilum downward.

The position of the seed during the period of soaking seems to affect the germination. A greater per cent of seeds germinate when, after soaking 24 hours, they are turned 180°. This position and method of treatment seems more favorable than either soaking in a horizontal position or in the position to be retained during germination.

Germination begins earlier at a high temperature (35°), but fewer seeds germinate than at a lower (24°).

The shape and position of the peg are dependent, in some measure, upon the position of the seed during germination. Noll found the shape of the peg to be constant for each position. In my experiments I have found it constant in but two positions,- the two horizontal positions, edgewise and flat. In these instances the peg was similar to that which he describes. The horizontal flat position gives a seedling with a large peg on the concave side of the hypocotyl. The horizontal edgewise gives a smaller swelling on the concave side and larger ones opposite the right and left halves of the testa. The frill formation which Noll shows in Fig. 2 of his article in "Landwirtschaftliche Jahrbücher" is very rarely found in this variety of pumpkin seed. The peg as shown in his Fig. 3 as characteristic for seeds in the oblique position is also of rare occurrence.

The peg seems to be most effective in the seeds placed horizontally flat and horizontally edgewise.

Too high temperature causes the seedling, when the seed is placed vertically downward,to grow so rapidly that the hypocotyl is carried out from the testa before the peg is formed and thus the two halves are not properly separated for the release of the cotyledons.

Induction is but a slight factor in the formation of the peg. The turning of the seedling 180° induces the formation of a peg in very few instances.

Contact is not a factor in the formation of a peg. Seeds grown in moist air have pegs similar to those grown in sand.

Gravity is the principal stimulus in the formation of the peg. This, however, does not explain all shapes. A second and not yet determined stimulus Noll designated as "autonom".

The optimal conditions for germination are, according to Noll, the horizontal flat position with not too high a temperature. The results of these experiments would not be exactly the same. The oblique upward position, in a moderately dry soil at not too high a temperature gives the highest per cent of germination. The functioning of the peg, however, is not so effective as when the seed lies in a horizontal position.

EXPERIMENTS

Experiment I. Pumpkin seeds after soaking 24 hours were placed in sand in positions as follows:

v. u. - vertically placed, with the hilum directed upward.

v. d. - vertically, with the hilum downward.

h. e. - horizontally, resting on edge.

h. f. - horizontally, resting upon the flat surface.

o. u. - obliquely upward, 30° to 45° from the perpendicular, hilum upward.

o. d. - obliquely downward, hilum downward.

After covering with damp filter and inverted crocks, seeds were placed to germinate at a temperature of 24° C.

Experiment II. A series of three experiments similar to I. except that the seeds were germinated in saw-dust and the temperatures were 22° C, 24° C, and 35° C.

Experiment III. Exactly like II. except that seeds after soaking were germinated in sand.

Experiment IV. Repetition of III.

Experiment V. Repetition of III.

Experiment VI. Seeds in the six positions, as indicated under I. were placed between damp filter papers in petri dishes and kept at laboratory temperature 24° C.

Experiment VII. A series of three experiments, at laboratory temperature, in which seeds were placed in the six positions, as in I. after soaking as follows: M,in horizontal position 24 hours; N,in positions in which they were to be left to germinate, and O, in position as in second, and then turned 180° when planted. The seeds germinated in moist air.

Experiment VIII. Like III., IV., V., except that to study the peg more carefully, a hole was made for the reception of the seed.

Experiment IX. Seeds were soaked in three positions,- v. u., v. d., and h. f. for 24 hours, then placed in sand, the hilum in every instance being downward. Holes were made to receive the seeds.

Experiment X. Similar to IX., but an additional set of seeds were soaked in v. u. position 24 hours, placed in sand in same position for another 24 hours, and then placed in v. d. position to germinate. Holes were made for the seeds.

Experiment XI. Series of four experiments germinated at 22° C.; placed in moist air in the six positions as indicated in I. after soaking 18 hours in position as follows: M, all seeds soaked in horizontal position; N,seeds soaked in the six positions they were to occupy for germination; O,seeds soaked in the six positions and turned 180° when planted 24 hours later; P,seeds soaked in the six positions and turned 180°, 24 hours after planting in sand.

Experiment XII. Similar to XI., but soaked 24 hours and then placed in sand. Holes were made for seeds. Temperature was 22° C.

Experiment XIII. Similar to X.; temperature 22° C.

Experiment XIV. Similar to X., but with degrees of moisture as a factor; temperature the same for all,- 22° C. Quantities of water to each crock of sand approximately as follows:

R - 50 cc. water; S - 135 cc. water; T - 220 cc. water; U - 305 cc. water; V - 390 cc. (saturation point)

Experiment XV. Similar to XII. except seeds were soaked 24 hours and germinated in moist air. Temperature, 22° C.

EXPLANATION OF PLATES

Plate I.- To show the Total Germination for Seeds in Each of Six Positions. Experiments I., II., III., IV., V., VI., VIII.

Plate II.- To show the Total Germination for Seeds Germinated Hilum Downward after Soaking in Different Positions:

M - horizontal

N - six positions to be retained

O - six positions but turned 180° when planted

P - six positions but turned 180° 24 hours after planting. After remaining 24 hours, seeds are turned hilum downward. Experiments VII., XI., XII., and XV.

Plate III.- To Show the Effect of Different Degrees of Moisture upon Total Germination of Seeds. Seeds were soaked in a horizontal position 24 hours, and were then placed in sand, hilum downward. Experiment XIV.

Plate IV.- To Show the Effect of Different Degrees of Moisture upon the Total Germination of Seeds. Seeds were soaked hilum downward and planted in the same position. Experiment XIV.

Plate V.- To Show the Effect of Different Degrees of Moisture upon the Total Germination of Seeds. Seeds were soaked hilum upward 24 hours and were then planted hilum downward. Experiment XIV.

Plate VI.- To Show the Effect of Different Degrees of Moisture upon the Total Germination of Seeds. Seeds were soaked hilum upward 24 hours; after remaining 24 hours in sand in the same position, they were turned hilum downward. Experiment XIV.

Plate VII.- To Show the Effect of Different Temperature upon the Total Germination of Seeds. Temperature of 22° C. Experiments II., III., IV., V., VIII.

Plate VIII.- To Show the Effect of Different Temperature upon the Total Germination of Seeds. Temperature of 24° C. Experiments II., III., IV., V., VIII.

Plate IX.- To Show the Effect of Different Temperature upon the Total Germination of Seeds. Temperature of 35° C. Experiments II., III., IV., V., VIII.

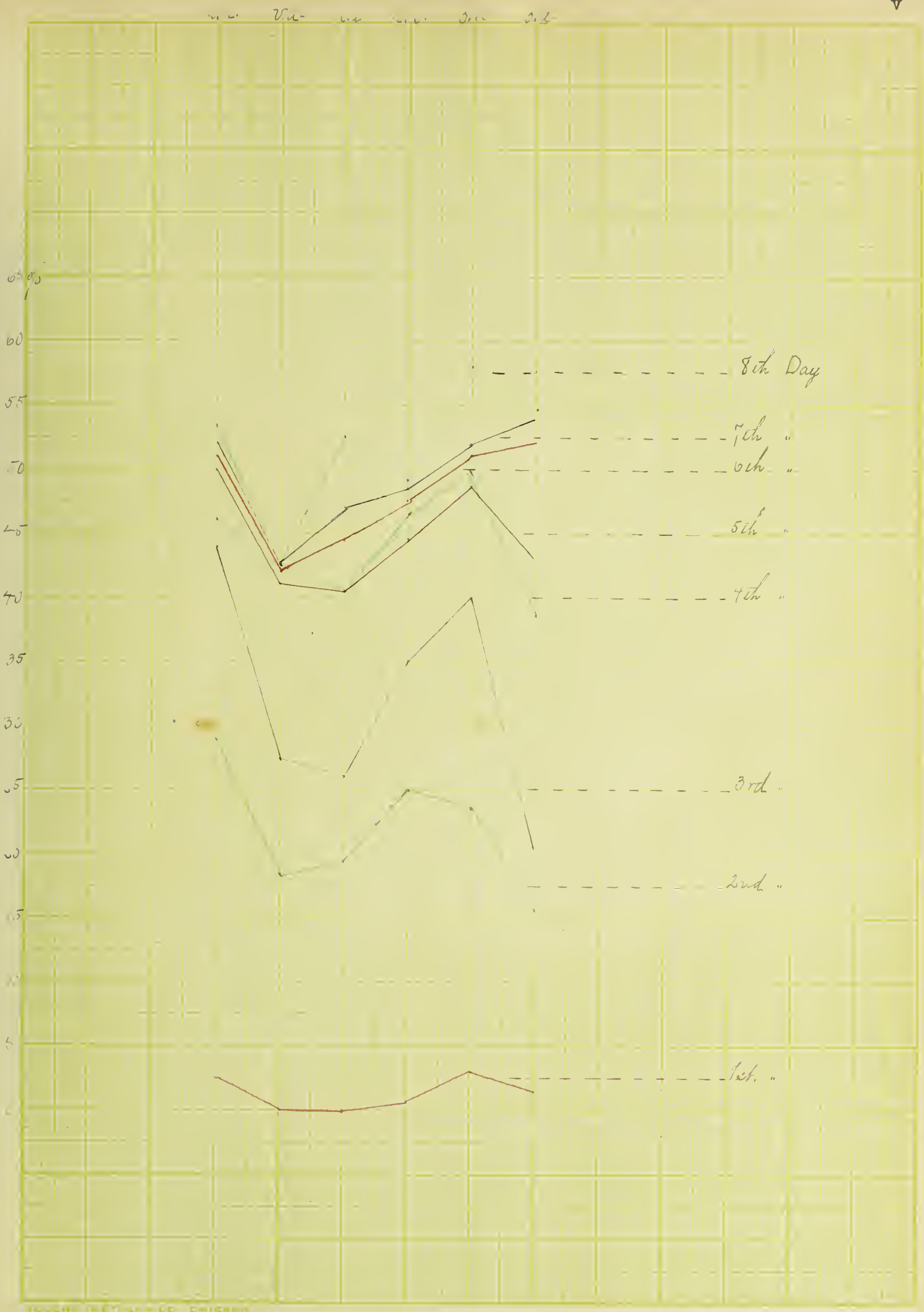

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Plate I.

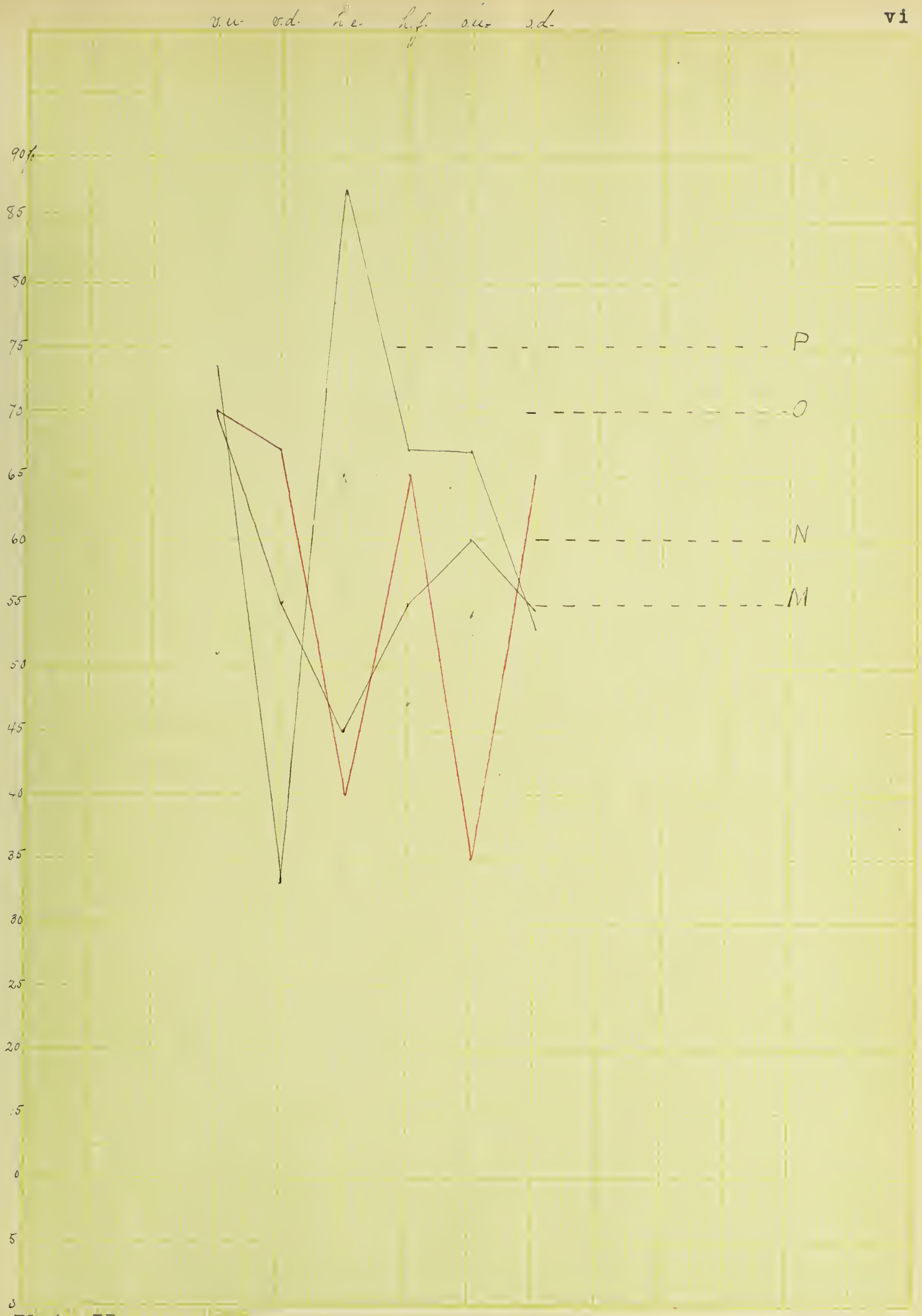
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Plate II.

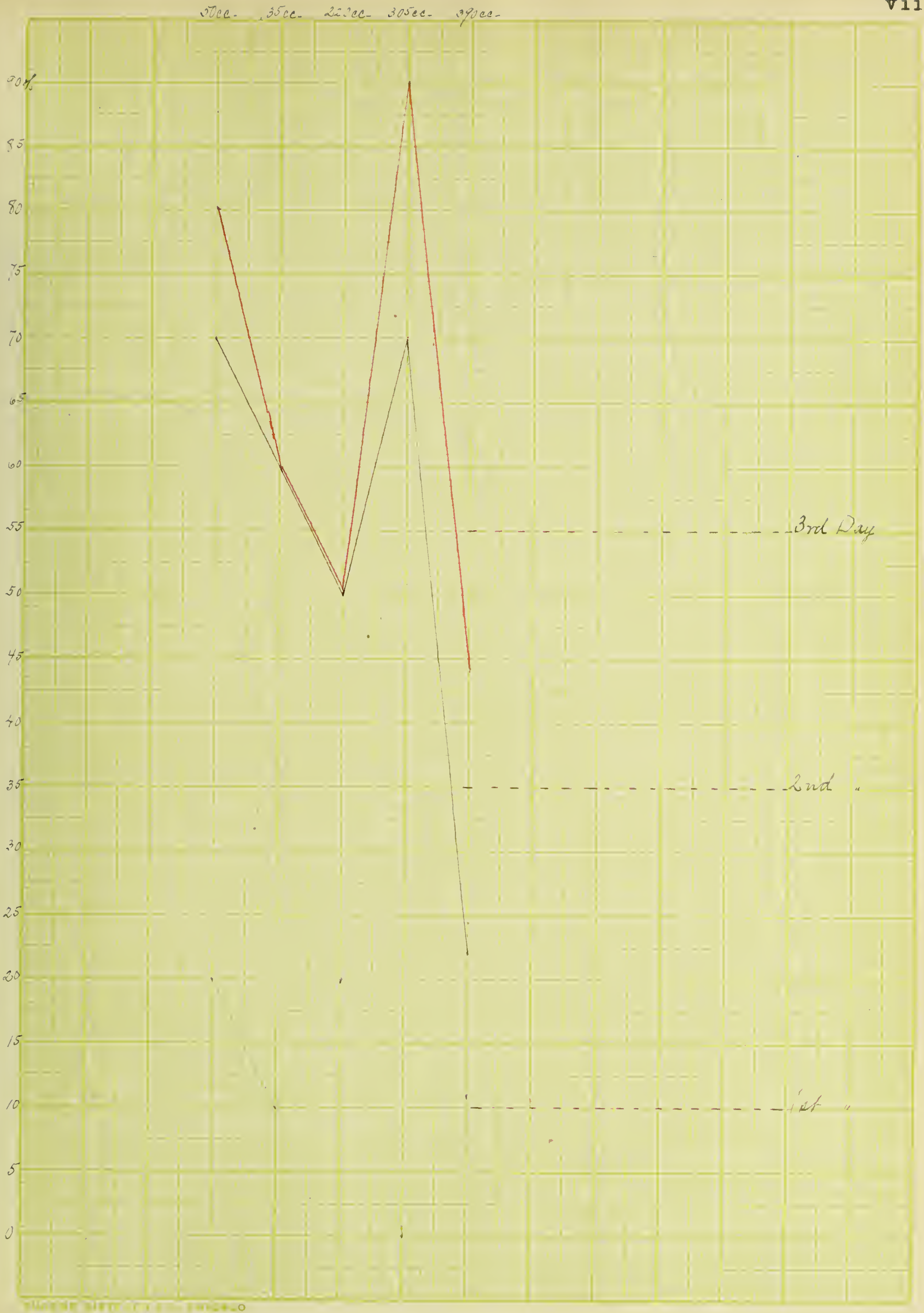
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Plate III.


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Plate IV.

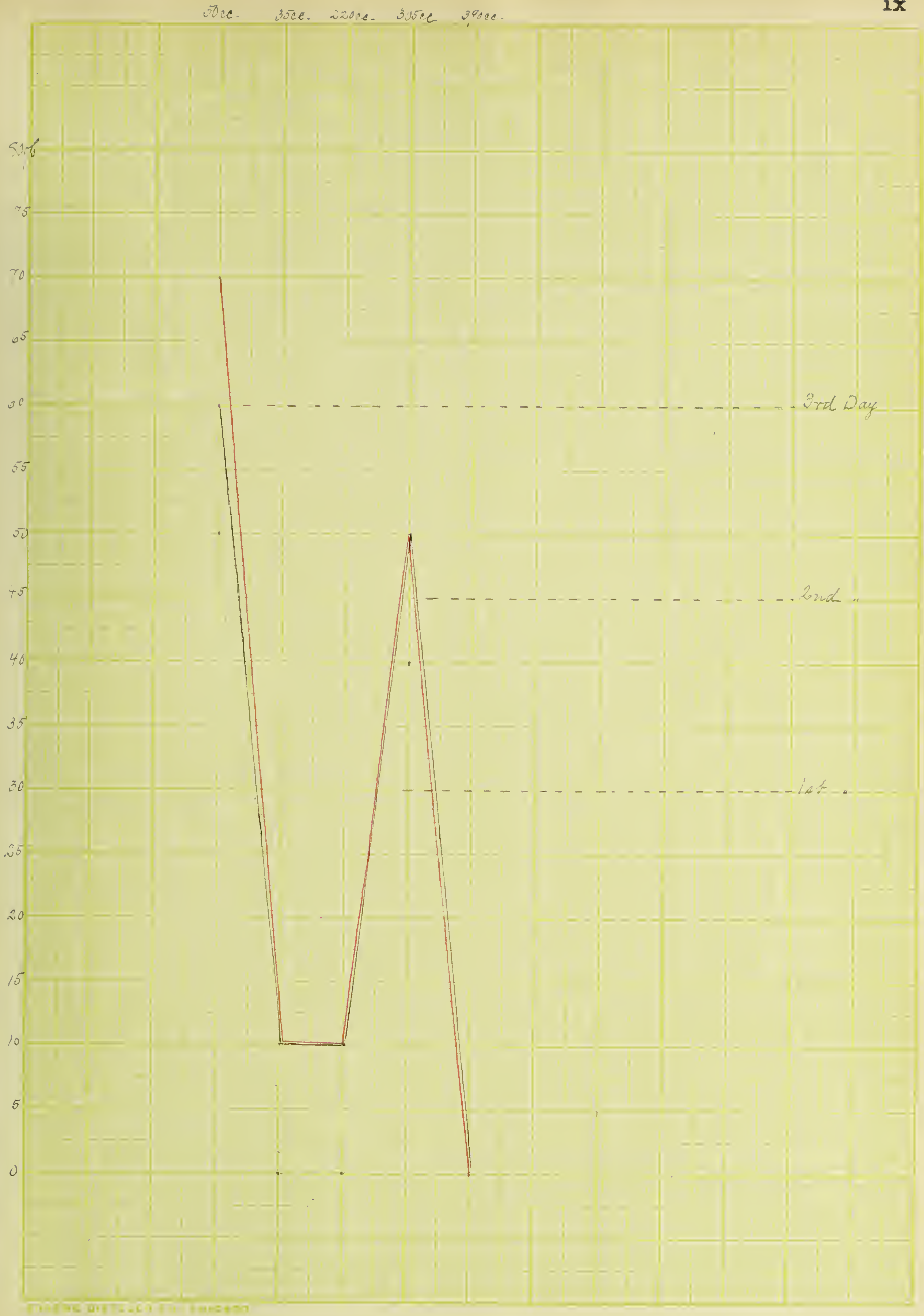
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Plate V.

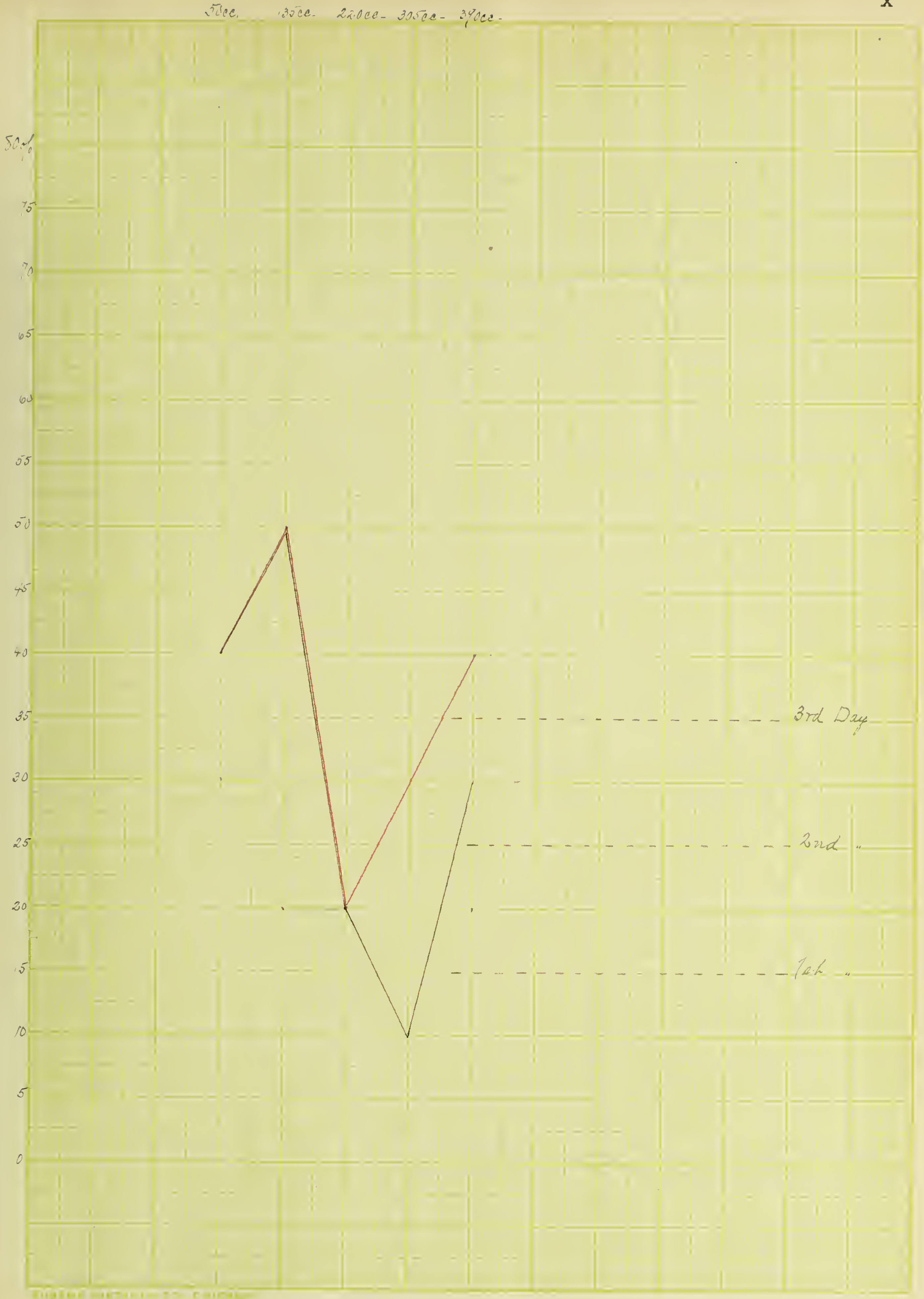
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Plate VI.

Plate VII.

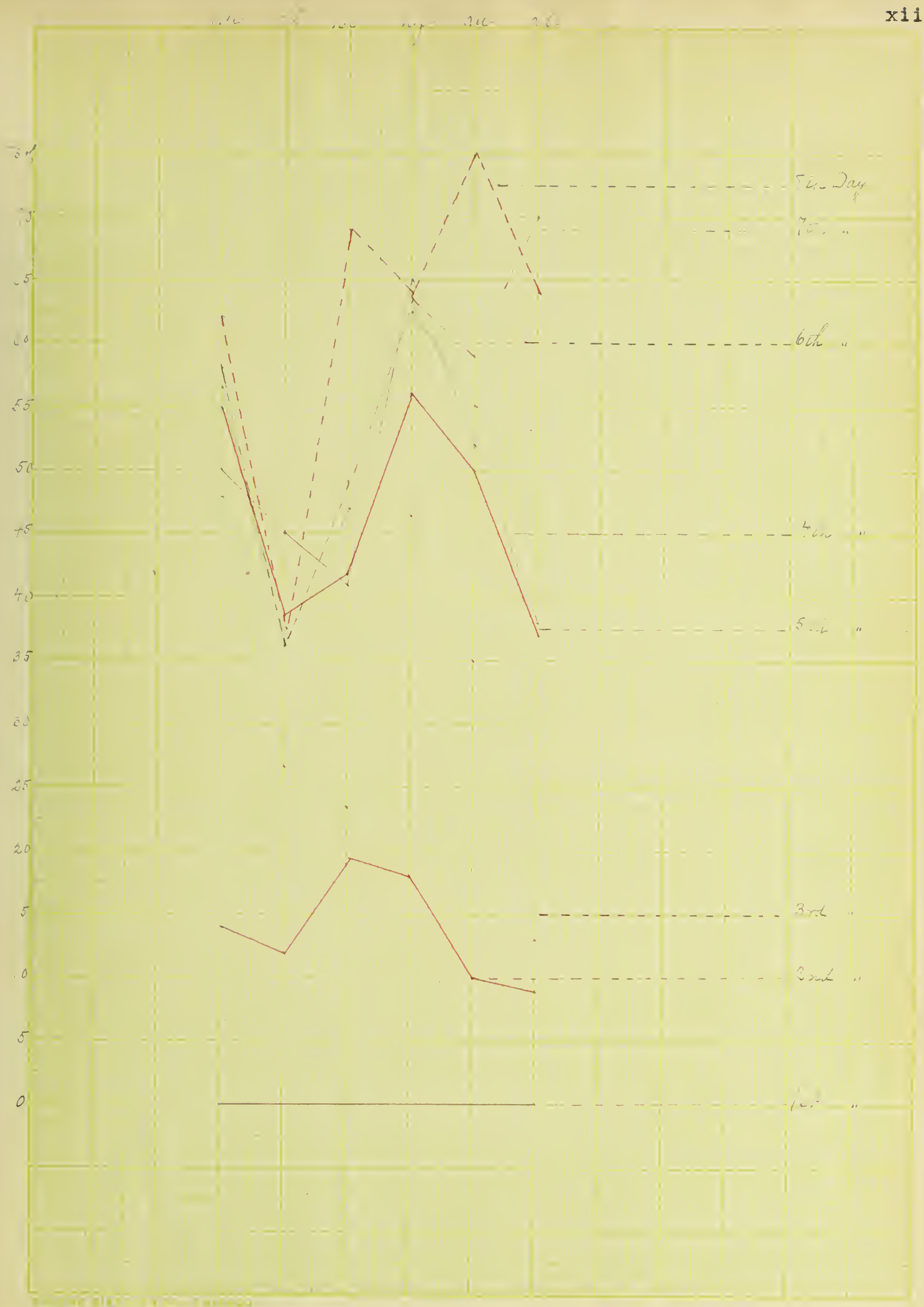

Plate VIII.

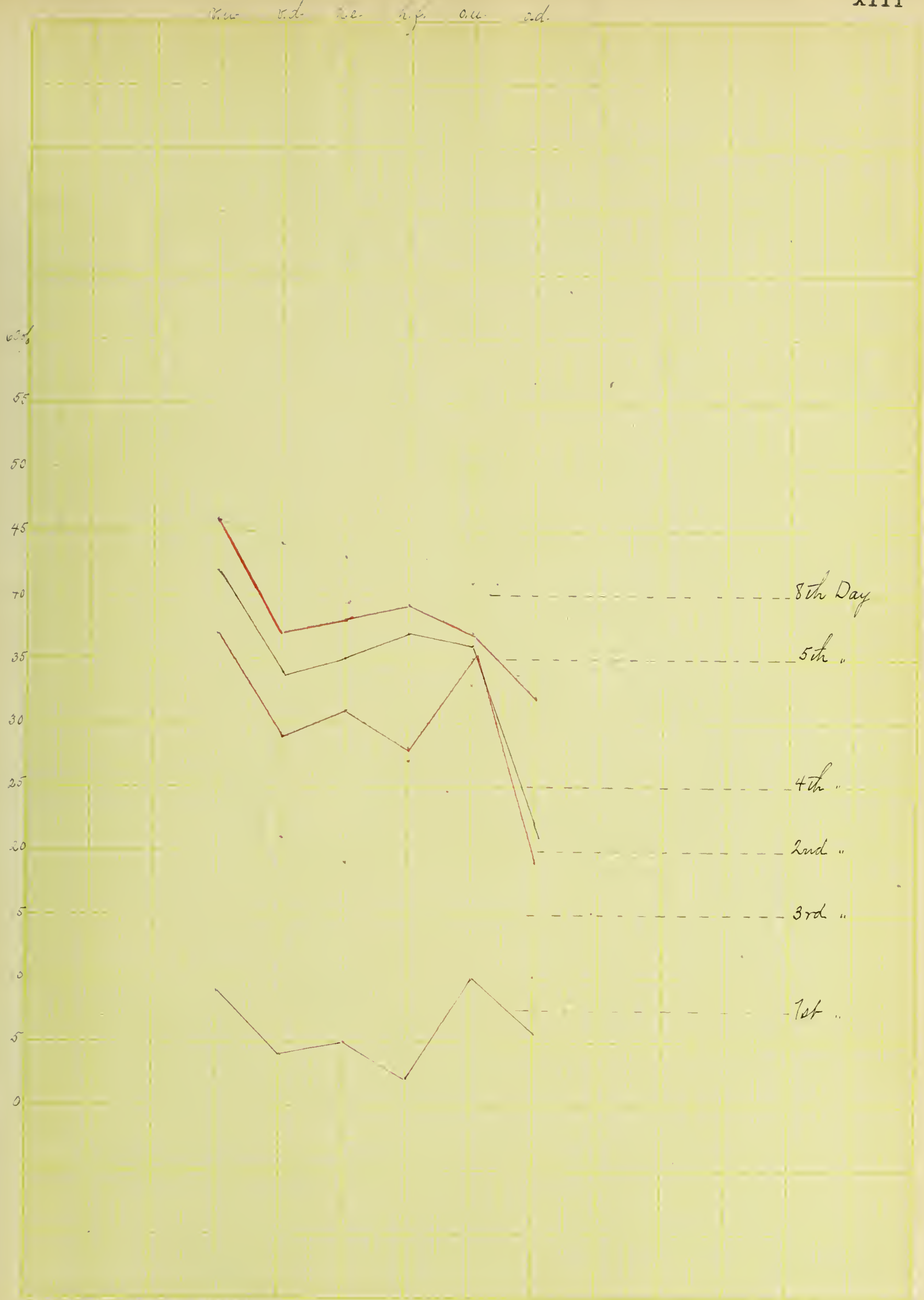
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Plate IX.